Propagation Modeling

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LONG TERM GOALS

Develop electromagnetic propagation models for use in operational or engineering propagation assessment systems.

OBJECTIVES

Develop an advanced unified hybrid radio propagation model based on parabolic equation and ray-optics methods for both surface-based and airborne applications. This model is named the Advanced Propagation Model (APM) and is the model used in the Advanced Refractive Effects Prediction System (AREPS). Complete analysis of radio signal strength measurements from NOAA radio transmitters and compare with APM predictions for low altitude mobile radio applications over land. The results will be documented in an open literature publication. Other objectives are to evaluate the Janaswamy model for use in APM; integrate it into APM as required, and continue efforts to modify APM (or develop a new model) to allow finer height resolution to improve resolution of the surface wave.

APPROACH

We develop parabolic equation, ray optics, waveguide, and other models as necessary to produce both accurate and efficient models to be used in propagation assessment systems. In many cases we can use variations of existing models to achieve this goal, but sometimes completely new models are necessary. Once developed, these models are compared to other models and to experimentally collected propagation data for verification of accuracy. We stay abreast of other researchers' newest models by reading current literature, participating in propagation workshops, and attending conferences as appropriate. We continually examine new modeling techniques that may offer improvements in prediction accuracy or execution time. There is a strong international exchange of

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ideas and techniques in this area, as some important work is performed outside of the USA. This ongoing project has developed a hybrid ray optics/parabolic equation propagation model for assessing the effects of the atmosphere and the environment in general on electromagnetic emissions in the range of 2 MHz to 57 GHz for both surface based and airborne transmitters.

In order to establish APM as a truly joint operational model for use by all the military services, a small-scale validation effort was conducted to measure radio signal strength for low altitude mobile receivers. The results of this validation effort will determine the APM's suitability as a propagation model for specific Marine and Army mobile applications. The signals of opportunity used were two NOAA weather radio transmitters in southern California: KEC-62 (San Diego) and WXL-87 (Yuma). The San Diego transmitter operates at 162.4 MHz and the Yuma transmitter at 162.55 MHz. All propagation paths were entirely over land where paths ranging from very steep and rugged terrain to relatively flat desert were included. Meteorological information was obtained via climatology and real-time soundings from met stations near the transmitter sites.

This project is divided into two tasks: (1) Low Altitude Propagation Effects For Mobile Radio Communications, PI Amalia Barrios; and (2) Non-constant Surface Impedance Model For APM, PI Dr. Richard Sprague.

WORK COMPLETED

Low Altitude Propagation Effects for Mobile Radio Communications

This work was performed as part of an extension of data collected previously in the northeastern U.S., which showed APM to perform very well for low altitude geometries over land [1]. Radio signal strength data was taken over the course of 10 days from Dec 2003 to July 2004 with a mobile receiver. The chosen route began at the SSC SD facility, heading eastward on Interstate 8. The route ended near Yuma, and the data collection continued with the receiver traveling westward along the same route returning to the SSC SD facility. Signals from both the KEC-62 and WXL-87 transmitters were received along this route. Radiosonde data was obtained from permanent sounding stations located at Miramar (NKX) and Yuma Proving Ground (1Y7). Both Digital Terrain Elevation Database (DTED) and United States Geological Survey (USGS) data were also obtained to analyze the sensitivity of predictions to the resolution of the different terrain databases. Analysis of this data has been completed and results have been documented and will be submitted for publication in IEEE Transactions on Antennas and Propagation.

HF Propagation Modeling

Efforts this year centered on completing evaluation of a new model for propagation prediction at low altitudes. The model, developed by Ramakrishna Janaswamy [2], offers the promise of improvements in both the accuracy and the speed of execution of predictions over the model currently in use in APM. We previously implemented a test-bed version of the model and have systematically included and tested several capabilities required by any model envisioned as replacing APM. Results of these efforts have shown that predictions from the new model are, in most instances, comparable to those of APM. Speed of execution is also comparable in that the new model requires two extra Fourier transform executions per range step which somewhat mitigates the gains achieved by doing away with grazing angle calculations for terrain and rough ocean surface calculations.

For HF surface wave propagation over terrain, the new model is slower since the poles of the reflection coefficient, which correspond to the surface wave modes, have to be determined at each range step. We also have found that, in all cases, accuracy of HF predictions is very similar to APM.

In summary then, we have found that the Janaswamy model provides little or no advantage, either in accuracy or speed of execution over the model in APM. If we were developing a prediction capability from the start, the Janaswamy model would be a competitive option, but it does not provide enough of an advantage to warrant replacement of the model currently in use in APM.

RESULTS

Low Altitude Propagation Effects for Mobile Radio Communications

Both real-time soundings and climatology were used for this analysis. Climatology was considered due to the high percent occurrence of both surface-based and elevated ducts from the San Diego met station. Surface-based ducts occurred as much as 40% of the time during August and well over 50% of the time during the summer months from May through September for elevated ducts. Climatology was also used for the WXL-87 paths due to the relatively poor resolution of the soundings from the 1Y7 met station. Refractivity profiles were constructed from soundings and climatology and used for input into APM.

Both USGS and DTED terrain data were also applied in order to quantify errors associated with using different terrain resolutions. Figure 1 shows the topographical area of Southern California, the transmitter and met station locations, and the receiver route. Final results show for the low altitude geometries present in this analysis, the refractivity did not have a significant impact, with the exception of one measurement day on 30 June 2004, in which transmissions from the Santa Barbara station (KIH-34) were received due to the existence of an elevated duct. APM predictions based on USGS terrain produced lower root mean square (RMS) errors than those using DTED, but the standard deviations were statistically the same based on both terrain databases. For the graphics shown here, all APM predictions are based on standard atmosphere and USGS terrain.

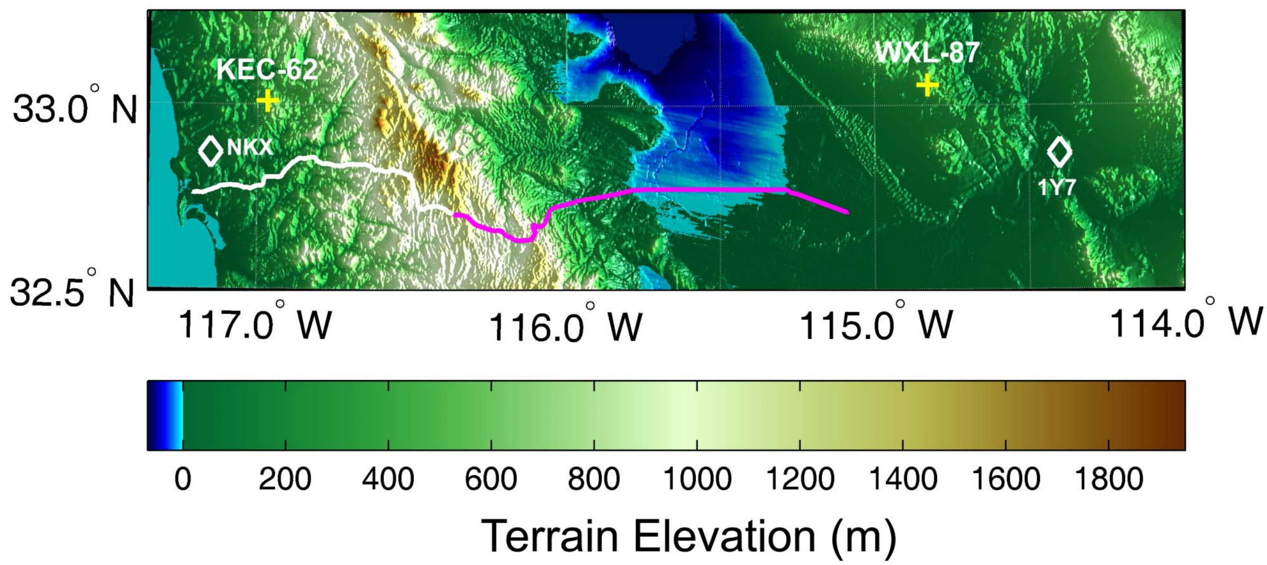


Figure 1. Location of NOAA transmitters, met stations, and receiver route.
[White and pink curves show receiver route from SSC SD to Yuma vicinity. The path from SSC SD to the yellow "+" shows receiver lat/lon of the KEC-62 (San Diego) transmitter. The pink path shows receiver lat/lon of the WXL-87 (Yuma) transmitter. The white "◊" symbols indicate the location of the KEC-62 and WXL-87 transmitters.]

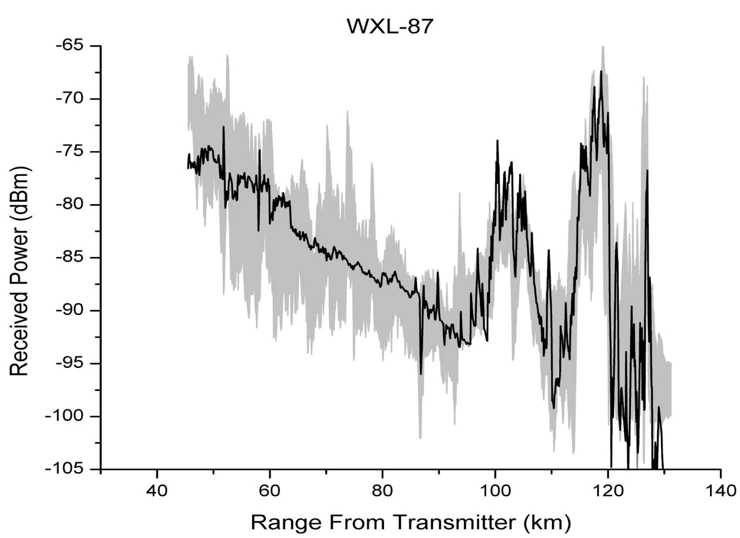


Figure 2. APM predictions (black line) and 95% confidence interval (shaded area) of WXL-87 observations over nine days (18 data sets).

APM performed extremely well for measurements from the WXL-87 transmitter. The proximity of the receiver from the transmitter varied from 40 km to over 130 km. Figure 2 shows the 95% confidence interval of 18 data sets collected from the WXL-87 transmitter over nine measurement days. For all measurement days the RMS error varied from 5.7 to 13.0 dBm, and the standard deviation varied from 5.7 to 11.9 dBm.

For the KEC-62 transmitter APM did not show as good agreement with observations. For the sake of ease in displaying predictions and observations as a function of range from the transmitter, the receiver path for this route was split into those portions east and west of the KEC-62 longitude position. Figure 3 shows the 95% confidence interval of 18 data sets collected from the KEC-62 transmitter over nine measurement days for those portions west (Fig. 3a) and east (Fig. 3b) of the transmitter. For all measurement days the RMS error varied from 12.4 to 17.2 dBm, and the standard deviation varied from 9.7 to 17.3 dBm.

HF Propagation Modeling

As we indicated at the 2005 program review, implementation of the Donohue and Kuttler shift-map terrain algorithm within the Janaswamy propagation model leads to significantly differing results with respect to APM. These differences remain after verification of our implementation of the shift-map algorithm in the new model. In particular, the new model predicts significantly more energy in shadow regions than APM. This enhancement is somewhat predictable given the differences in the calculation methods between the two programs, but the differences are somewhat more than expected. The examples shown in the original Donohue and Kuttler paper [3] also suggest enhanced shadow region energy but not to the extent seen in the Janaswamy model. Our plans under this effort for next year included an extensive comparison of both models to data. Ultimately, this is the only way questions such as these can be answered, short of comparison to other models, such as Geometric Theory of Diffraction models.
Since we have chosen to discontinue this effort after this year, we want to be sure that the conclusion we reached concerning the implementation of the new model in APM, which is based on comparison of both model predictions to each other and to 'standard' models such as MLAYER and Berry's HF surface wave model, is supportable with real data. To that end we performed a comparison of both

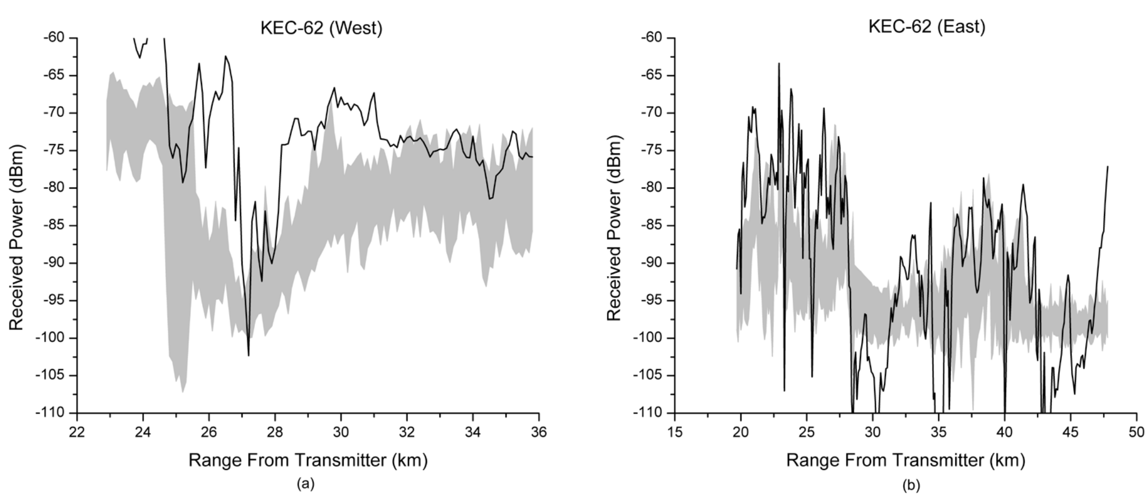
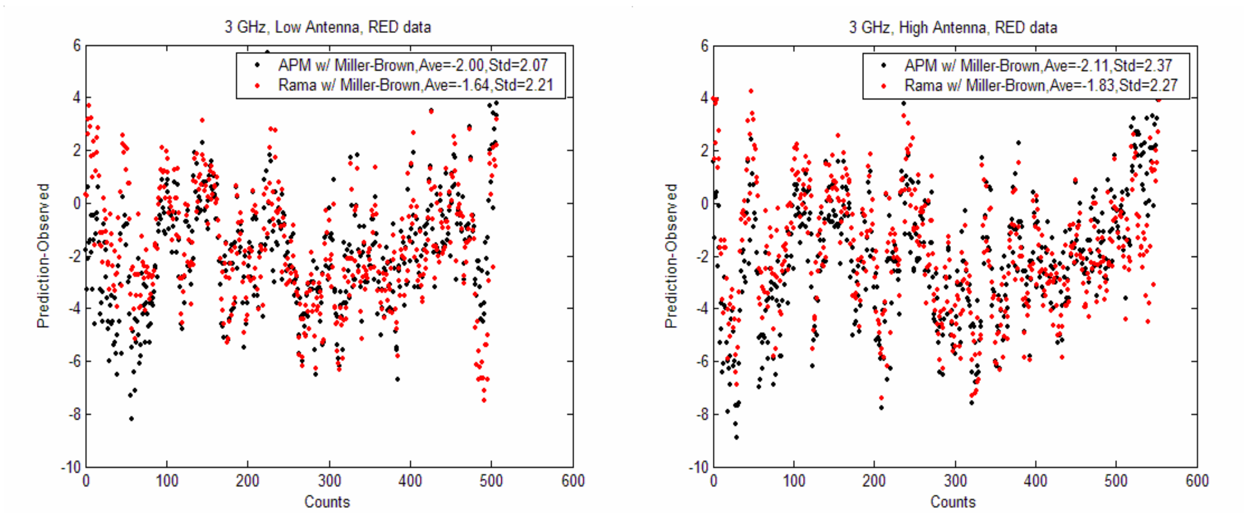


Figure 3. APM predictions (black line) and 95% confidence interval (shaded area) of KEC-62 observations over nine days (18 data sets).

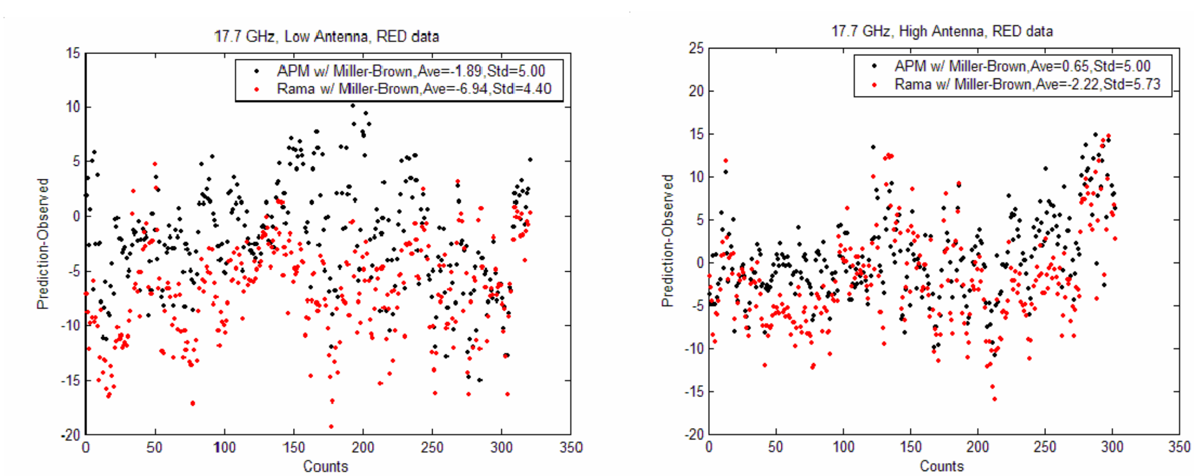
models, using the same rough ocean model, to data collected during the RED campaign in Hawaii in 2001. Some results of that comparison are shown in Figures 4 and 5.

Figure 4 shows a scatter plot comparing APM and the Janaswamy model predictions of basic transmission loss to the RED data set at 3 GHz. Figure 4a shows the results for a low receiving antenna (~ 5 m above the sea) and Figure 4b shows similar results for a high receiving antenna (~12 m). The parameter shown is predicted-observed where each value is in dB. The horizontal axis is just a counter of data points that is generally tied to time (earlier data at low counts, later data at high counts). Also indicated are basic statistics relating to model accuracy.



(a) (b)

Figure 4. Comparison of model predictions from APM and the Janaswamy model to RED data. 3 GHz data for low (a) and high (b) antennas.



(a) (b)

Figure 5. Comparison of model predictions from APM and the Janaswamy model to RED data. 17.7GHz data for low (a) and high (b) antennas.

For the 3 GHz data, the average difference is slightly better for both low and high antennas, but the differences are not significant. The standard deviation indicates the spread in predictions is about the same for the two models.

Figure 5 shows similar results for 17.7 GHz RED data. At this higher frequency, the average differences are significantly smaller for APM and the standard deviations are approximately the same for both models. This is true for both high and low antennas as indicated in the figure.

The Janaswamy model performs quite well against the measured data, as indicated above and in further comparisons to RED data not shown here. However, this data comparison confirms our earlier conclusion from model to model comparisons that the Janaswamy model does not provide improvement in prediction accuracy sufficient to warrant replacement of the APM model.

IMPACT/APPLICATIONS

The goal of this work is to produce an operational hybrid radio propagation model for incorporation into U.S. Navy assessment systems. Current plans call for APM to be the single model for all radio propagation applications. As APM is developed it will be properly documented for delivery to OAML, from which it will be available for incorporation into Navy assessment systems. The optimization of APM for low-altitude radio communications, along with applications focused on the Marines, not only benefits the services operating primarily on land, but also **unifies** the overall military EM performance assessment capability by having a single high-fidelity propagation model that performs equally well over land and sea and in the presence of anomalous propagation conditions.

TRANSITIONS

All APM modifications and added capabilities transition into the Tactical EM/EO Propagation Models Project (PE 0603207N) under PMW 180 which has produced the Advanced Refractive Effects Prediction System (AREPS). Academia and other U.S. government are also utilizing APM/AREPS. APM is currently being used by foreign agencies as the underlying propagation model within their own assessment software packages. APM has also been adopted as the preferred propagation model in the Evolved Sea Sparrow Missile (ESSM) International Simulation (IntSim) program created by NAWC-WD. IntSim is a NATO program with the following participating countries: Australia, Belgium, Denmark, Germany, Netherlands, and Norway. APM involvement within IntSim is via the Ship Air Defense Model (SADM), which is the RF propagation assessment module within IntSim and was developed by BAE Systems, Australia.

RELATED PROJECTS

This project is closely related to the synoptic and mesoscale numerical analysis and prediction projects pursued by NRL Monterey.

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